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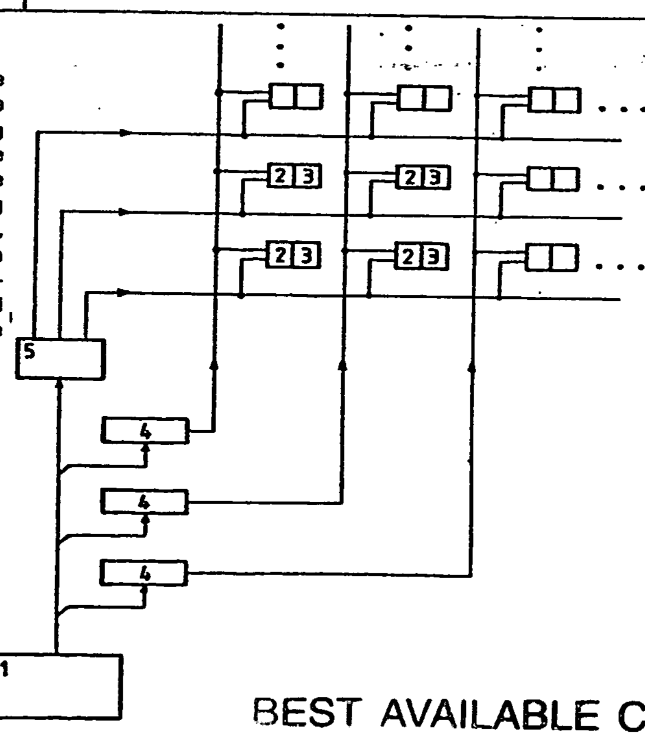
(54) **Phase-shift control for a phased array antenna.**

(57) In a phase-shift control for a phased array antenna the antenna modules are arranged in rows and columns. The phase shift control is provided with central computing means for calculating from the beam direction to be determined and the frequency of the energy emitted, the terms in the mathematical expression for the phase setting for the separate phase shifters in the antenna modules, which terms are the same for all phase shifters, and a computing chip present in each antenna module for determining the desired phase setting from the terms determined by the central computing means and the position of the separate phase shifters in the array.



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Phase-shift control for a phased array antenna

The invention relates to a phase shift control for a phased array antenna, whereby the antenna modules comprising the phase shifters are arranged in rows and columns, which phase shift control is provided with computing means for calculating the desired phase setting for the separate phase shifters from at least the beam direction to be determined, the frequency of the energy emitted, and the position of each phase shifter in the array.

Such a phase-shift control is known from, for example, M.I. Skolnik, "Introduction to Radar Systems", 2nd ed., McGraw-Hill Kogakusha, Ltd., 1980, p. 323, where the phase shift for the respective antenna modules is determined in a beam-steering computer. If these phase shifts must be determined for each radar pulse emitted, an exceptionally large computer capacity will be required for the usually large number of antenna modules. This capacity can be limited by refraining from a phase setting per pulse and enabling this setting after each transmission of a given pulse series or by performing the phase setting in accordance with certain patterns. The present invention has for its object to provide such a phase-shift control that with a strongly reduced computer capacity still a phase setting per pulse and per antenna module can be achieved.

According to the invention, the computing means thereto comprises central computing means for calculating, from the beam direction to be determined and the frequency of the energy emitted, the terms in the mathematical expression for the phase setting, which terms are the same for all phase shifters, and a computing chip present in each antenna module for determining the desired phase setting from the terms determined by the central computing means and the position of the separate phase shifters in the array. The complete computer processes to be performed are therefore split into processes performed centrally and processes performed locally, i.e. on antenna-module level.

If in a Cartesian coordinate system the x- and y-axes determine the antenna plane and the z-axis the antenna main axis and it is assumed that the beam direction makes an angle Θ with the z-axis and that the projection of the beam direction on the x-y plane makes an angle φ with the x-axis, then for phase differences Ψ_x and Ψ_y between the phase shifters adjoining the x- and y-directions:

$$\Psi_x = \frac{2\pi}{\lambda} d_1.\cos\varphi.\sin\Theta,$$

$$\Psi_y = \frac{2\pi}{\lambda} d_2.\sin\varphi.\sin\Theta,$$

where d_1 is the distance between two antenna modules in the x-direction and d_2 the distance between two antenna modules in the y-direction. If all antenna modules in the x-y plane are arranged above and next to each other, then for the phase shift for antenna module m,n:

$$\Psi_{m,n} = m.\Psi_x + n.\Psi_y.$$

If on the other hand the rows of antenna modules are shifted alternately a distance of $\frac{1}{2}d_1$ in the x-direction with respect to each other, this phase shift will be:

$$\Psi_{m,n} = (m + \tfrac{1}{2})\Psi_x + n.\Psi_y,$$

while maintaining the row and column configuration in the array. For simplicity, the first situation in the array will be considered here, so that

$$\Psi_{m,n} = m.\frac{2\pi}{\lambda} d_1.\cos\varphi.\sin\Theta + n.\frac{2\pi}{\lambda} d_2.\sin\varphi.\sin\Theta.$$

In the case of using a space-fed phased array antenna, either a lens array or a reflect array, a correction must be made in the expression for $\Psi_{m,n}$. This correction allows for the change from a spherical to a plane phase front. To this effect, the term $\frac{2\pi}{\lambda} C_{m,n}$ is included in the expression for $\Psi_{m,n}$. For the change from a purely spherical to a plane phase front,

$C_{m,n} = \sqrt{p^2 + x^2 + y^2} - p$, where p is the distance between the

centre of the horn radiator or other radiating element and the antenna plane. Such a purely spherical phase front is not present in practice. Since the $C_{m,n}$ values are found to be frequency-dependent and no mathematical relationship between $C_{m,n}$ and the frequency can be indicated, $C_{m,n}$ values for different frequency intervals must be established emperically.

During scanning with the antenna beam at certain elevations it is sometimes desirable to widen the beam. This requires the introduction of an additional phase shift $\varepsilon_{m,n}$; consequently, no plane phase front is formed, but say a quadratic phase front.

For phase shift $\Psi_{m,n}$ the relationship is now:

$$\Psi_{m,n} = K\left[\frac{m}{\lambda} d_1.\cos\varphi.\sin\theta + \frac{n}{\lambda} d_2.\sin\varphi.\sin\theta + \frac{1}{\lambda} C_{m,n}\right] + B.\varepsilon_{m,n},$$

where B=0 if no beam widening is applied; if applied, B=1. K is a constant. It is known to calculate this phase shift for each antena module separately in a beam-steering computer. According to the invention, the calculation is however split into processes performed centrally and processes performed locally in each antenna module. In the case of centrally performed processes, the results can be fed to all antenna modules simultaneously.

The terms $a = \frac{K}{\lambda} d_1.\cos\varphi.\sin\theta$, $b = \frac{K}{\lambda} d_2.\sin\varphi.\sin\theta$ and $c = \frac{K}{\lambda}$ can be calculated centrally. Entry of the values d=m, e=n, $f=C_{m,n}$ and $g=\varepsilon_{m,n}$ into the computing chip of each antenna module is done once only, leaving in each chip only the calculation of

$$\Psi_{m,n} = a.d + b.e + c.f + B.g.$$

The d, e, f and g values can be stored permanently in each computing chip; they can however also be supplied by the central computing means each time before the array is activated. In such a case, the B-value can be supplied as well; it is also possible to enter this value separately or simultaneously with the a, b and c values when the array is in the active mode.

The division between centrally and locally performed processes may be effected other than described above. For instance, the values $a = \cos\varphi.\sin\Theta$, $b = \sin\varphi.\sin\Theta$ and $c = \frac{1}{\lambda}$ can be determined centrally and, after entry of the values $d = K.m.d_1$, $e = K.n.d_2$, $f = K.C_{m,n}$ and $g = \varepsilon_{m,n}$ in the respective computing chips, the phase shift $\Psi_{m,n} = c.\{a.d + b.e + f\} + B.g$ locally, or the values $a = \frac{1}{\lambda}\cos\varphi.\sin\Theta$, $b = \frac{1}{\lambda}\sin\varphi.\sin\Theta$ and $c = \frac{1}{\lambda}$ centrally, and after entry of the values $d = K.m.d_1$, $e = K.n.d_2$, $f = K.C_{m,n}$ and $g = \varepsilon_{m,n}$ into the computing chips, the phase shift $\Psi_{m,n} = a.d + b.e + c.f + B.g$ locally.

The invention will now be described with reference to the accompanying figure, showing a block diagram of an embodiment of the phase-shift control in accordance with the invention.

In this figure, the numeral 1 represents the central computing means. The computing chip of each antenna module is designated by 2 and the associated phase shifter by 3. The antenna modules are thus formed by the elements 2 and 3 jointly. The data transmissions from the central computing means 1 to the separate antenna modules 2, 3 are routed via the buffer elements 4 by means of the addressing circuit 5.

Reading of the values $d = m$, $e = n$, $f = C_{m,n}$ and $g = \varepsilon_{m,n}$ into the separate computing chips takes place before the array antenna assumes the active mode. The d-values are the same for the antenna modules lying in a column. All buffer elements 4 are therefore filled with a certain m-value from the central computing means. The e-values are the same for the antenna modules lying in a row. To enter these values, all buffer elements 4 are filled with the same n-value from the central computing means, namely m successive times with a new n-value. The f- and g-values are different for each antenna module. To enter these values, the buffer elements are filled m successive times with a certain $C_{m,n}$ or $\varepsilon_{m,n}$ value from the central computing means. In all cases,

the addressing circuit 5 ensures that this information is entered into the antenna modules.

Since the $C_{m,n}$ values are frequency-dependent, it is preferable to enter several of such values in each antenna module to ensure that, when the array is in the active mode, an appropriate $C_{m,n}$ value is available for the locally performed calculations with each frequency change.

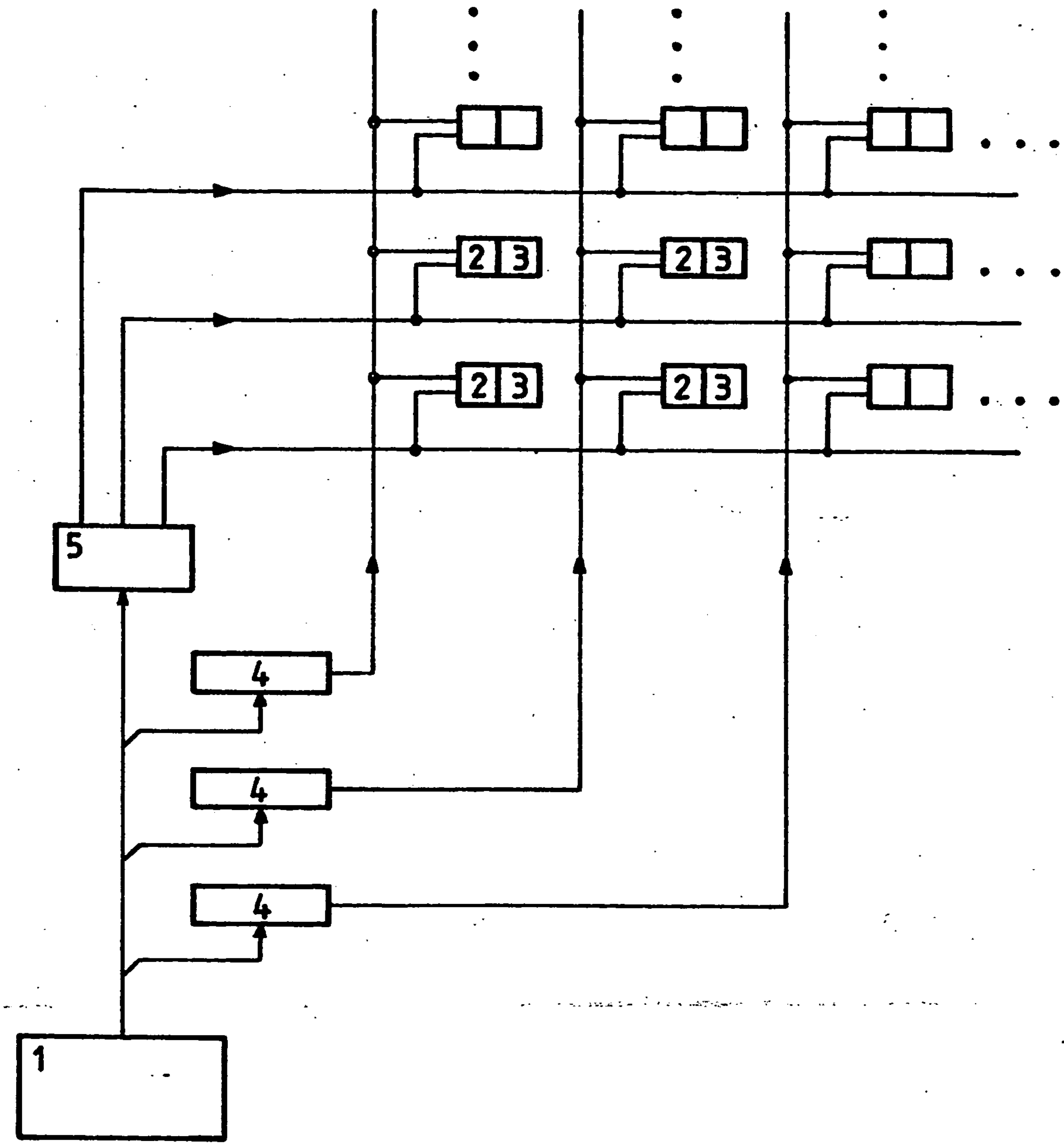
With the array antenna in the active mode, the values $a = \frac{K}{\lambda} d_1.\cos\varphi.\sin\Theta$, $b = \frac{K}{\lambda} d_2.\sin\varphi.\sin\Theta$ and $c = \frac{K}{\lambda}$, supplied to the antenna modules each time, are the same for all antenna modules. The buffer elements 4 are filled successively with the same a-, b- or c-value from the central computing means 1, while the addressing circuit 5 again ensures that this information is entered into the respective antenna modules. During the transmission of a radar pulse and the listening to an echo the a-, b- and c-values for a subsequent radar pulse are entered into the antenna modules. In the dead time before the transmission of the next radar pulse, only a command signal is sent to all antenna modules simultaneously in the same way as the a-, b- and c-values, whereupon the array switches to the newly selected beam direction.

Claims:

1. Phase-shift control for a phased array antenna, whereby the antenna modules comprising the phase shifters are arranged in rows and columns, which phase shift control is provided with computing means for calculating the desired phase setting for the separate phase shifters from at least the beam direction to be determined, the frequency of the energy emitted, and the position of each phase shifter in the array, characterised in that the computing means comprises central computing means for calculating from the beam direction to be determined and the frequency of the energy emitted, the terms in the mathematical expression for the phase setting, which terms are the same for all phase shifters, and a computing chip present in each antenna module for determining the desired phase setting from the terms determined by the central computing means and the position of the separate phase shifters in the array.

2. Phase-shift control as claimed in claim 1, whereby a space-fed phased array antenna is applied, characterised in that frequency-dependent correction values, required for the phase setting of the phase shifters individually and the change from a spherical to a plane phase front, can be entered into each computing chip.

3. Phase-shift control as claimed in claim 1 or 2, characterised in that a correction value, required for the phase setting of the phase shifters individually and the beamwidth setting, can be entered into each computing chip.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